Borneo Journal of Resource Science and Technology (2021), 11(1): 51-63
DOI: https:doi.org/10.33736/bjrst.3151.2021

Minimum Effective Dose of Chlorantraniliprole and Chromafenozide to Control Oil Palm Bunch Moth *Tirathaba mundella* Walker

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Received: 23 March 2021 Accepted: 19 May 2021 Published: 30 June 2021

ABSTRACT

The bunch moth, *Tirathaba mundella,* is one of the leading pests in oil palm estates established on peatland. Severely infested male inflorescences usually would fail reaching anthesis. Reduction in the number of inflorescences at anthesis stage would suggest less food source and breeding ground for oil palm pollinating weevils, *Elaeidobius kamerunicus,* thus, affecting the fruiting percentage of oil palm and its yield. Despite to be less detrimental to the environment, biopesticide usages in the field is losing favour due to its slower rate of killing compared with that by conventional chemical pesticides, shorter persistence in the environment and susceptibility to unfavourable environmental conditions. The use of high host specificity chemical pesticides, such as chlorantraniliprole and chromafenozide are gaining popularity in pest management regimes. In this study, the optimum dose for chlorantraniliprole and chromafenozide in controlling *T. mundella* was assessed to provide valuable information for sustainable oil palm pest management. Several dosages of pesticide were evaluated for their effectiveness against *T. mundella* in a 7-year-old oil palm estate for six months. Based on the results obtained, application of 30 g or 40 g active ingredient (a.i.) per ha chlorantraniliprole were recommended to provide the longest protection period. To make plan for an effective pest management that could reduce material and labour cost per ha as well as the risks in developing pesticide resistance among pest, 30 g a.i per ha of chlorantraniliprole is recommended to be rotated with 25 g a.i. per ha chromafenozide for a total of four rounds in a year.

Keywords: Chlorantraniliprole, Chromafenozide, *Tirathaba mundella*

INTRODUCTION

Tirathaba mundella Walker is a predominant pest infesting both inflorescence and fruit bunches of oil palm *Elaeis guineensis* in Malaysia, causing fruit deformation and bunch abortion in cases of severe infestation. At present, the common method to control *T. mundella* in the field is using biopesticides that is known to have less detrimental effect on beneficial insect. However, chemical insecticides that are pollinating-weevil friendly such as chlorantraniliprole and chromafenozide (Su *et al*., 2020) are gaining popularity because they display better pest controlling effect than biopesticide. Since the efficacy of *B. thuringiensis* pesticides can be affected by a number of environmental factors such as sunlight, temperature, pest density and presence of associated filter feeding non-target organisms (Dunkle & Shasha, 1989), chlorantraniliprole and chromafenozide are expected to become an important component in very near future pest management regimes. However, the optimum and cost-effective rate of both chlorantraniliprole and chromafenozide in controlling *T. mundella* in the field has yet to be established. Two field experiments were therefore initiated to obtain the optimal dosage of chlorantraniliprole with biological insecticide as a baseline control for assessing the efficacy of the different dosages of chromafenozide and chlorantraniliprole against oil palm bunch moth, *T. mundella* Walker.

Chlorantraniliprole is an anthranilic diamides insecticide and chromafenozide is an insect growth regulator. Su (2016) recommended both of these pesticides to control *T. mundella* in oil palm because they are found to be pollinating weevil, *Elaeidobius kamerunicus* friendly.

In this study, the optimal dosage of chromafenozide in rotation with chlorantraniliprole were determined. Both chromafenozide and chlorantraniliprole were used in rotation to slow down the development of insecticide resistance. Both insecticides have different mode of action. Chromafenozide is classified as an insect growth regulator that disturbs normal growth and insect development, which in time can kill the insect (Yu, 2014). Chlorantraniliprole is a ryanodine receptor modulator that activates ryanodine receptors to stimulate the uncontrollable release of calcium and, as a result, the targeted insects would experience muscle paralysis and ultimately death of the insect (Yu, 2014).

In this study, two additional insecticides namely *Bacillus thuringiensis*-based insecticide, and indoxacarb were included in the evaluation to serve as positive control. All the insecticides tested were known to be friendly to oil palm natural pollinators, *E. kamerunicus.* The use of these insecticides in *T. mundella* management is therefore highly recommended. This paper presented the optimum and cost-effective rate of chlorantraniliprole and the optimum dosage of chromafenozide to be used in rotation with chlorantraniliprole.

MATERIALS AND METHODS

Experimental Site and Design

Two experiments were conducted to determine (1) the optimal dosage of chlorantraniliprole used to control *T. mundella* and (2) the optimum dosage of chromafenozide to be used in rotation with chlorantraniliprole. Both experiments were carried out in a 7-year-old oil palm estate established on peat. The design of the experiment was complete randomised block design with four replicates. Oil palms were planted 8.5 m apart in a triangular pattern in the estate. Each planting row consisted of 11 palms, and each planting block consisted of four rows of palms. A field drain separated each block. For each treatment, a block that consists of four rows of palms was considered as a replicate. With this planting layout, the middle two rows of palms (22 palms) in each block were selected as sampling palms while the balance change to remaining two rows which were grown next to the field drain were treated as guard palms. The size of the experimental plot for optimal dosage of chlorantraniliprole was 8.75 ha, whereas the experimental plot size for determining the optimum dosage of chromafenozide in rotation with optimal dosage of chlorantraniliprole was 3.75 ha.

Optimal Dosage of Chlorantraniliprole

In the experiment to determine the optimal dosage of chlorantraniliprole, two types of insecticides were tested and compared to chlorantraniliprole, which were *B. thuringiensis*-based insecticide, and indoxacarb. *B. thuringiensis*-based insecticide and indoxacarb were chosen as they are among the common pesticides used in Sarawak oil palm estates. A total of seven treatments were assessed, consisted of a negative control, four dosages of 34.9% w/w chlorantraniliprole (10 g active ingredient (a.i.) per ha, 20 g a.i. per ha, 30 g a.i. per ha and 40 g a.i. per ha), one recommended dosage (6.6 X 10^6 I.U) of *B. thuringiensis*-based insecticide with 17,600 I.U/mg and one recommended dosage (45 g a.i. per ha) of indoxacarb. The rate used as shown in Table 1.

Optimal Dosage of Chromafenozide in Rotation with Chlorantraniliprole

Three different dosages (25 g a.i. per ha, 37 g a.i. per ha and 50 g a.i. per ha) of chromafenozide were tested with optimal dosage (30 g a.i. per ha) of chlorantraniliprole. The pesticide application regimes were set with only four rounds application in a year against oil palm bunch moth. Four rounds of pesticide applications are regarded as economically feasible. The insecticide application rate and rotation mechanism tested are shown in Table 2 and Table 3.

Evaluation of Efficacy of Insecticide Application

Prior to the application of insecticides, the infestation status of *T. mundella* in all trial plots was assessed to get the baseline data. The field census was carried out every month post-treatment for of six months to determine optimal dosage for chlorantraniliprole; whereas for experiment to determine optimal dosage of chromafenozide, the census was conducted monthly for a period of twelve months. The pest infestation census was carried out based on the parameters as described in Su *et al.* (2020). The total number of clean fruit bunches, moderately infested fruit bunches and severely infested fruit bunches were recorded.

Table 1. Insecticides application rate for chlorantraniliprole optimal dosage trial

Treatment	Trade name / Product	a.i. Rate of product per ha	Rate per 16 litres of water	Product rate per ha
Absolute control (T1)	-	-	-	-
34.9% w/w Chlorantraniliprole (T2)	Dupont Altacor 34.9 WG	10 g	1.60 g	28.70 g
34.9% w/w Chlorantraniliprole (T3)	Dupont Altacor 34.9 WG	20 g	3.00 g	57.30 g
34.9% w/w Chlorantraniliprole (T4)	Dupont Altacor 34.9 WG	30 g	4.60 g	85 g
34.9% w/w Chlorantraniliprole (T5)	Dupont Altacor 34.9 WG	40 g	5.20 g	115 g
Bacillus thuringiensis (T6)	Dipel ES 17,600 I.U/mg	6.6 X 10^6 I.U	30 ml	562 ml
30.0% w/w Indoxacarb (T7)	Tatum	45 g	8.0 g	150 g

Note: Recommended dosage per 16 L water is based on spray volume of 300 L/ha.

Table 2. Insecticides application rate and rotation schedule for chromafenozide optimal rates trial

Treatment	Product rate per ha	a.i. of product per ha	Rotation schedule	Total rounds per year
Chlorantraniliprole 34.9% w/w rotated with C*hromafenozide* 4.9% w/w (T1)	85 g 500 ml	30.0 g 25.0 g	One round at interval of four months rotated with one round at interval of three months.	4
Chlorantraniliprole 34.9% w/w rotated with *Chromafenozide* 4.9% w/w (T2)	85g 750 ml	30.0g 37.0 g	One round at interval of four months rotated with one round at interval of three months.	4
Chlorantraniliprole 34.9% w/w rotated with *Chromafenozide* 4.9% w/w (T3)	85 g 1000 ml	30.0 g 50.0 g	One round at interval of four months rotated with one round at interval of three months.	4

Table 3. Rotation of insecticides application for chromafenozide optimal rates trial

Treatment	Rotation Intervals for Pesticide Application			
	November 18	March 19	June 19	October 19
85g *Chlorantraniliprole* 34.9% w/w rotated with 500 ml C*hromafenozide* 4.9% w/w (T1)	Chlorantraniliprole	Chromafenozide	Chlorantraniliprole	Chromafenozide
85g *Chlorantraniliprole* 34.9% w/w rotated with 750 ml C*hromafenozide* 4.9% w/w (T2)	Chlorantraniliprole	Chromafenozide	Chlorantraniliprole	Chromafenozide
85g *Chlorantraniliprole* 34.9% w/w rotated with 1000 ml C*hromafenozide* 4.9% w/w (T3)	Chlorantraniliprole	Chromafenozide	Chlorantraniliprole	Chromafenozide

Statistical Analysis

Data for both trials were subjected to square root transformation prior to analysis of variance (ANOVA) using statistical analysis system (SAS) version 8.2 (SAS Institute Inc., Cary, NC, USA). The means percentage of infestation were separated using Duncan New Multiple Range Test at a significant level of p=0.05.

RESULTS

Optimal Dosage of Chlorantraniliprole Against Oil Palm Bunch Moth, *T. mundella*

All treatments started with no significant difference in their mean percentage of clean fruit bunches as compared to the negative control in week 0 (Figure 1). After one month of treatment, the trial plots treated with *B. thuringiensis* insecticide, chlorantraniliprole and indoxacarb had outperformed the control plot with significantly higher mean percentage of clean bunches recorded (Figure 1) and reduced percentage of severely infested fruit bunches just a month after the application (Figure 2). The mean percentage of clean to light fruit bunches in all the treated fields were significantly higher than the negative control plot which had only 16.06% protected in week 4. This showed the insecticides' protection effect against *T. mundella*. In week 8, two months after treatment, the mean percentage of clean to light fruit bunches in plots treated with different concentrations of chlorantraniliprole increased further and offered more than 70% protection, which was significantly higher than the control, *B. thuringiensis* treated and indoxacarb treated plots. In week 8, plots treated with *B. thuringiensis* were also better than the control with higher mean percentage of clean to light fruit bunches. However, from week 12 onwards, there were no significant difference in mean percentage of clean to light fruit bunches among *B. thuringiensis* treated, indoxacarb treated plots and the negative control (Figure 1). But chlorantraniliprole treated plots continued to yield higher percentage of clean to light fruit bunches than other treatments.

For plots treated with 30 g and 40 g chlorantraniliprole, the mean percentage of clean to light fruit bunches were significantly higher than plots treated with either 10 g chlorantraniliprole or 20 g chlorantraniliprole. There were no significant differences in their performance between 10 g and 20 g of chlorantraniliprole as well as 30 g and 40 g of chlorantraniliprole. When reaching week 24, plots treated with 40 g chlorantraniliprole per ha had the highest percentage of clean to light fruit bunches among all the treatments. Oil palm plots treated with 40 g chlorantraniliprole per ha continually produced above 60% of clean to light fruit bunches throughout the six months monitoring period (Figure 1). Coming second is the field plots treated with 30 g chlorantraniliprole, which had above 60% of clean to light fruit bunches until week 20 before declined slightly to 52% in week 24. However, there was no significant differences in overall percentage of moderately infested fruit bunches (Figure 3), therefore it will not be included to assess the insecticides protection efficacy.

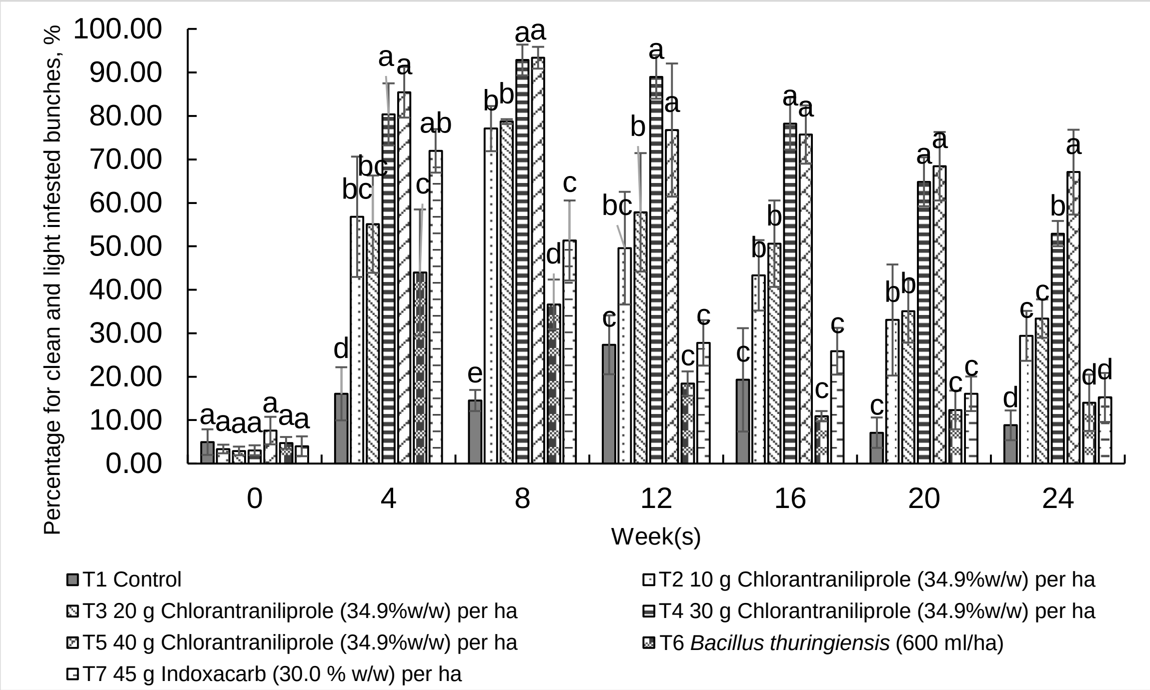

Figure 1. Mean percentage of clean fruit bunches for chlotantraniliprole optimal dosage trial. Means with the same letters within sampling period are not significantly different according to DNMRT at p=0.05. The vertical bars represent the standard error of means for four replicates

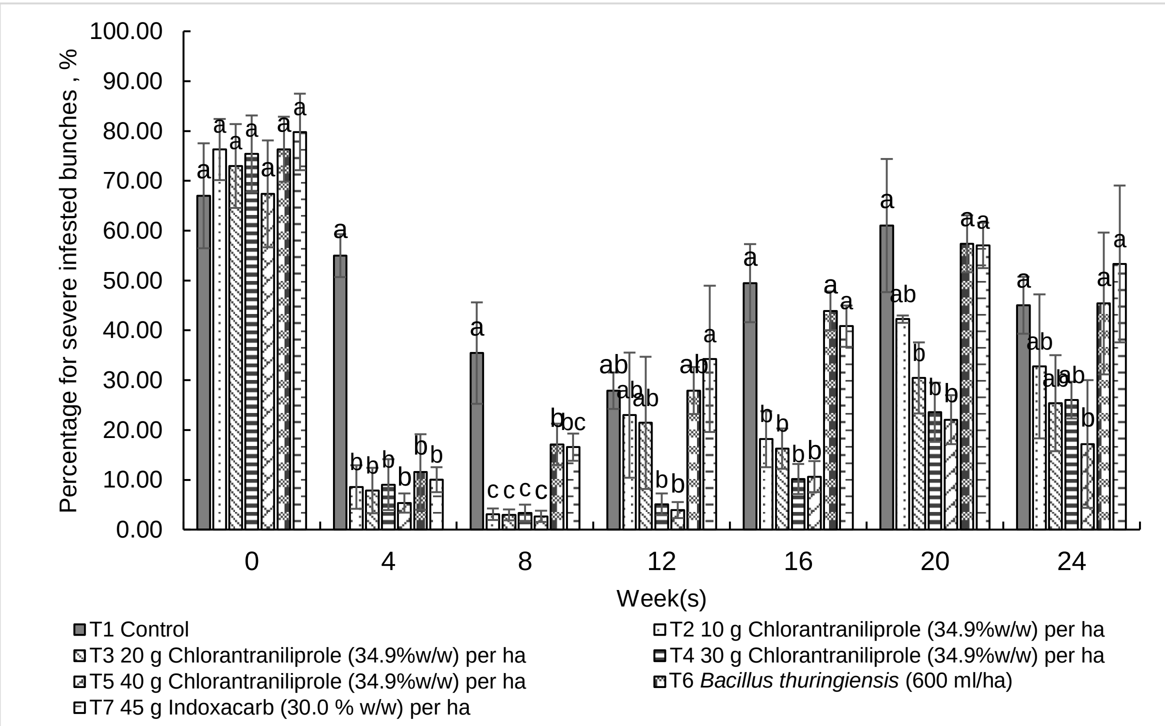

Figure 2. Mean percentage of severely infested fruit bunches for chlorantraniliprole optimal dosage trial. Means with the same letters within sampling period are not significantly different according to DNMRT at p=0.05. The vertical bars represent the standard error of means for four replicates

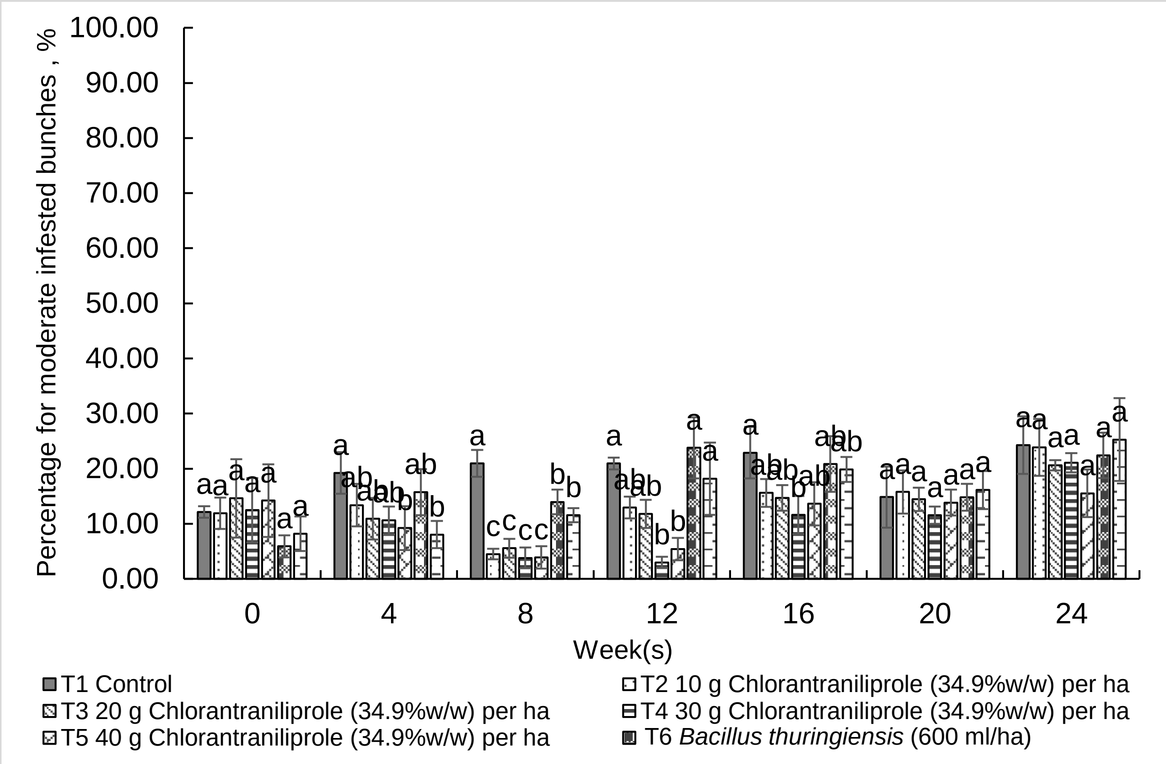

Figure 3. Mean percentage of moderately infested fruit bunches for chlorantraniliprole optimal dosage trial. Means with the same letters within sampling period are not significantly different according to DNMRT at p=0.05. The vertical bars represent the standard error of means for four replicates

For mean percentage of severely infested fruit bunches, there was no significant difference among all the treatments and negative control in week 0. The mean percentage of severely infested fruit bunches in control plots were fluctuated in the range of 28% to 67% during the six months of assessment. A substantial reduction in the percentage of severely infested fruit bunches was noted in all plots treated with insecticides in week 4 and 8. The mean percentage of severely infested fruit bunches in all the treated plots were significantly lower than negative control during the first and second month after treatment. However, from week 12 onwards, there was no significant difference in the mean percentage of severely infested fruit bunches obtained between *B. thuringiensis* treated plots and the negative control plots. For indoxacarb treated plots, significantly lower mean percentage of severely infested fruit bunches as compared to negative control was recorded in week 4 and week 8. However, from week 12 onwards, there was no significant difference in the mean percentage of severely infested fruit bunches obtained between indoxacarb treated plots and the negative control (Figure 2).

On contrast, chlorantraniliprole outplays the other treatments with relatively low mean percentage of severely infested fruit bunches throughout the six months monitoring period. For trial plots treated with 40 g chlorantraniliprole, the mean percentage of severely infested fruit bunches were persistently lower than the control plots from week 4 onwards until the end of month six. Plots treated with 30 g and 40 g of chlorantraniliprole per ha outperformed the rest of the treatments in week 12 and when reached week 24, trial plots treated with 40 g of chlorantraniliprole per ha had the lowest mean percentage of severely infested fruit bunches (Figure 2). Moreover, the one-time application with 40 g chlorantraniliprole per ha offered significant better protection for a period of six months against oil palm bunch moth than the other treatments. It reduced the number of severely infested fruit bunches (Figure 2) and increased number of clean to light fruit bunches (Figure 1). The duration of pest control exhibited by chlorantraniliprole in this trial is far more prolonged as compared to indoxacarb and *B. thuringiensis*.

The Efficacy of Different Dosages of Chromafenozide Rotated with Chlorantraniliprole

Chlorantraniliprole at 30 g a.i. per ha (equivalent to 85 g/ha of chlorantraniliprole 34.9% w/w) was used in rotation with chromafenozide at different dosage. The mean percentage of clean fruit bunches increased after a month of treatment in all three treatments tested (Figure 4). Two months after treatment, mean percentage of clean fruit bunches in Treatment 1 increased further to 70% while Treatment 2 and 3 at 64% and 57% respectively. Mean percentage of clean to light fruit bunches in Treatment 3 was significantly lower as compared to Treatment 1. However, from week 12 onwards, until week 52, there was no significant difference between all the treatments for mean percentage of clean to light fruit bunches (Figure 4).

Overall, one round of chlorantraniliprole applied in week 0 managed to maintain the mean percentage of clean to light fruit bunches over 60% for continuous 4 months before rotated with another round of chromafenozide in week 16. In week 20, one month after chromafenozide was applied, the mean percentage of clean to light fruit bunches increased further to more than 80%. The mean percentage of clean to light fruit bunches maintained at 60% to 80% from week 16 to week 28 for all the treatments. The third round of insecticide application using chlorantraniliprole (week 28) pushed up the overall mean percentage of clean fruit bunches to more than 80% and the number maintained at 75% in week 40 and week 44. The last round of insecticide application by adopting chromafenozide in week 44 managed to maintain the mean percentage of clean fruit bunches above 70% except for Treatment 3.

For mean percentage of moderately infested fruit bunches, there was no significant difference among all the three treatments throughout 52 weeks of monitoring period. The mean percentage of moderately infested fruit bunches in Treatment 1 fluctuated from as low as 10% in week 20 to as high as 26% in week 4. Treatment 2 on the other hand contained mean percentage of moderately infested fruit bunches from as low as 12% to as high as 26%. Similar trend was also observed in Treatment 3.

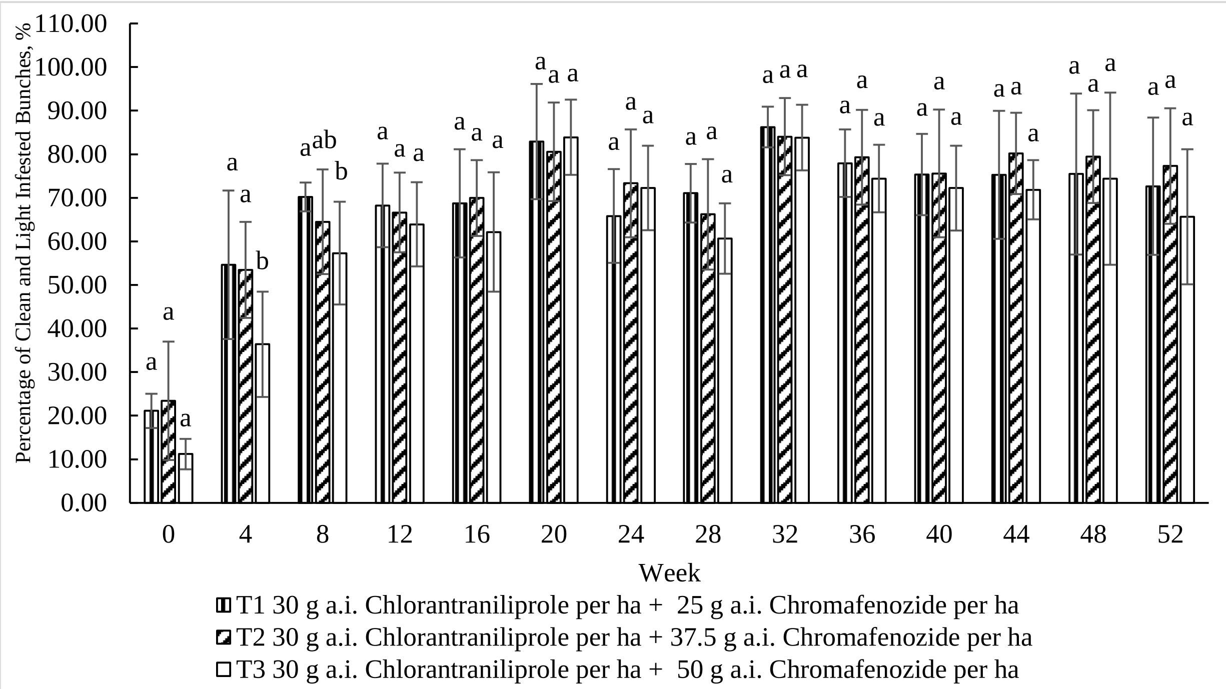

Figure 4. Mean percentage of clean to light fruit bunches for chromafenozide optimal dosage trial. Means with the same letters within sampling period are not significantly different according to DNMRT at p=0.05. The vertical bars represent the standard error of means for four replicates

Before treatment imposed (week 0), the mean percentage of severely infested fruit bunches fluctuated around 50% to 70%, which is not significantly different between all the treatments. However, in week 4, the mean percentage of severely infested fruit bunches reduced substantially to 19%, 19% and 39% for Treatment 1, Treatment 2 and Treatment 3, respectively. In week 8, the mean percentage of severely infested fruit bunches in all the three treatments reduced further and maintained below 15% until week 16, before the second round of insecticide chromafenozide was applied (Figure 5). In week 20, one month after the second round of insecticide application, the mean percentage of severely infested fruit bunches in all the three treatments reduced further to below 10% and maintained through week 24 before increased slightly in week 28. On the other hand, mean percentage of severely infested fruit bunches in both Treatment 1 and Treatment 2, maintained below 10% from week 32 until week 52, where chlorantraniliprole and chromafenozide were applied in week 28 and week 44 respectively. However, for Treatment 3, where 30 g chlorantraniliprole was rotated with 50 g chromafenozide per ha, the mean percentage of severely infested fruit bunches only reduced to below 10% in week 32 and week 48. Nevertheless, there was no significant difference among all the treatments on mean percentage of severely infested fruit bunches from week 4 to week 52.

Comparing all the three different dosages of chromafenozide applied, the mean percentage of clean (Figure 4), moderately infested (Figure 6) and severely infested fruit bunches (Figure 5) were no significant different throughout 52 weeks of monitoring period.

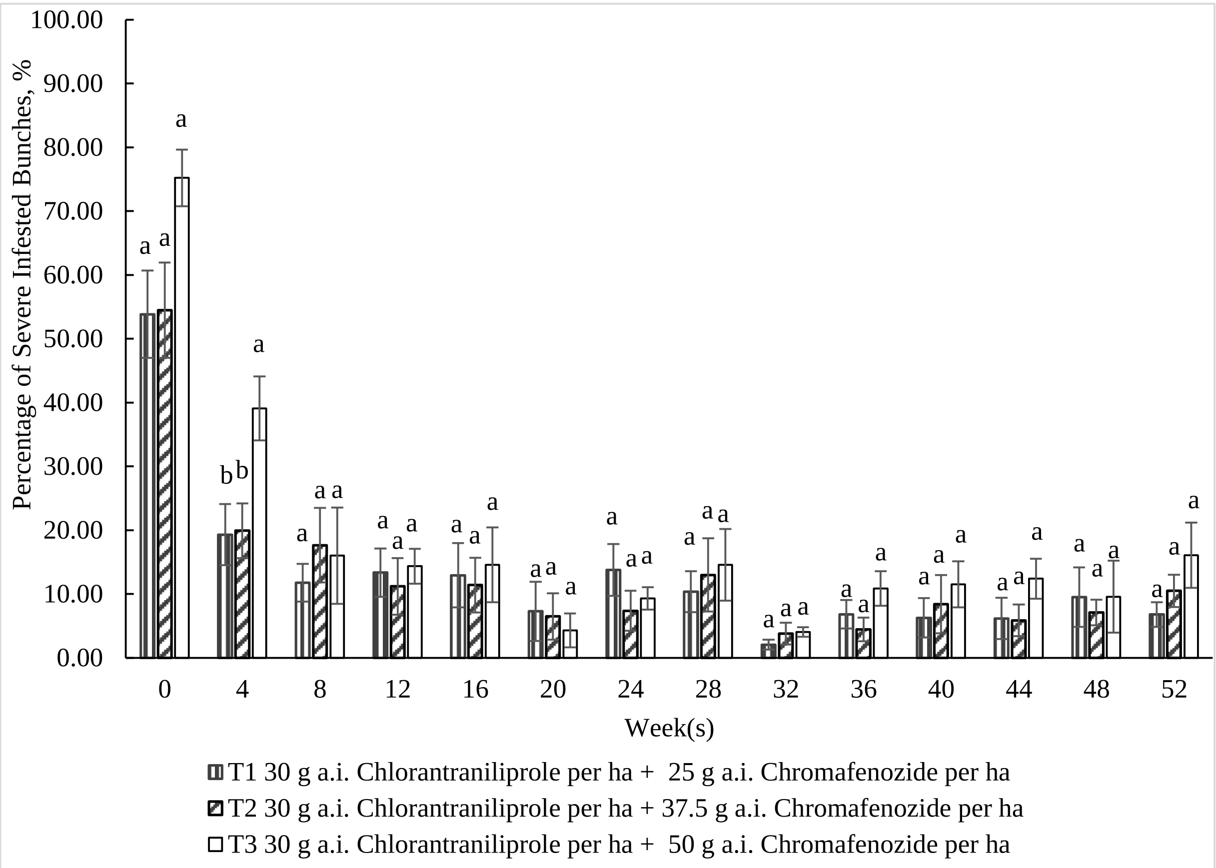

Figure 5. Mean percentage of severely infested fruit bunches for chromafenozide optimal dosage trial. Means with the same letters within sampling period are not significantly different according to DNMRT at p=0.05. The vertical bars represent the standard error of means for four replicates

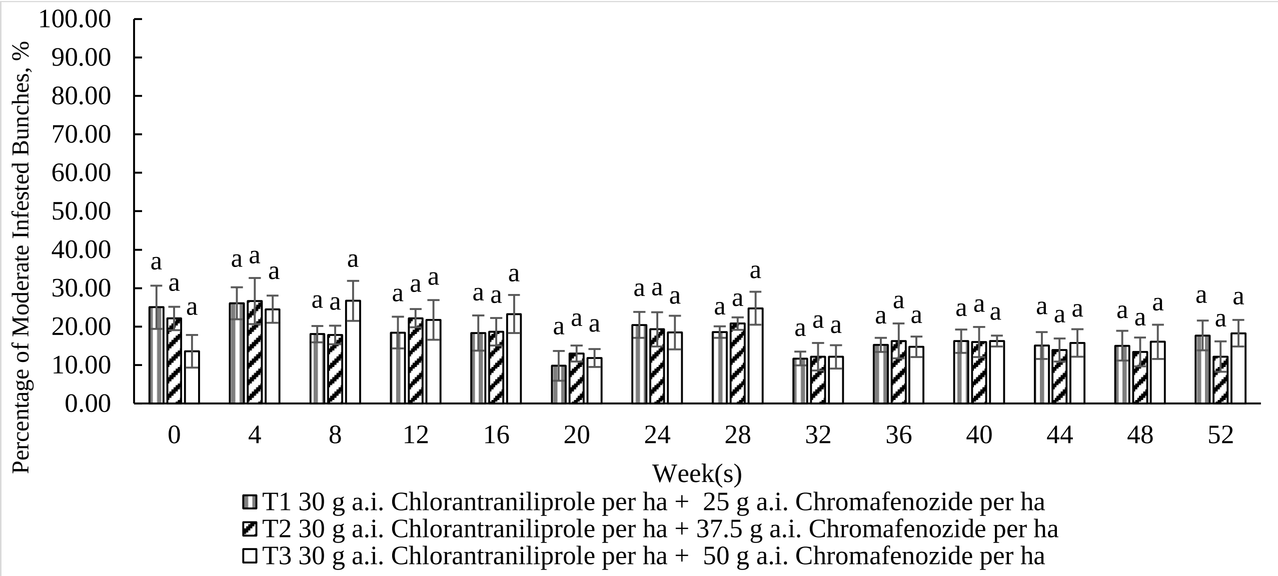

Figure 6. Mean percentage of moderately infested fruit bunches for chromafenozide optimal dosage trial. Means with the same letters within sampling period are not significantly different according to DNMRT at p=0.05. The vertical bars represent the standard error of means for four replicates

DISCUSSION

Optimal Dosage of Chlorantraniliprole Against Oil Palm Bunch Moth, *Tirathaba mundella*

Both *B. thuringiensis* insecticide and indoxacarb treatments increased the percentage of clean fruit bunches and declined the percentage of severely infested fruit bunches. However, the effect did not last for three months. The residue effect faded on the third month after application. Even though, biological insecticide, *B. thuringiensis* was introduced to the oil palm plantation to manage pest as it is ecologically friendly and demonstrate non toxicity against human, yet, the effectiveness of *B. thuringiensis* in controlling oil palm bunch moth was questionable as observed in this study. The rapidly waning insecticide effect of *B. thuringiensis* would require more frequent application to ensure the pest infestation can be effectively suppressed. Saharul *et al.* (2017) had suggested follow up applications of *B. thuringiensis* to be executed 34 and 84 days after treatment to prevent rapid re-emergence of pest population. Being a biological insecticide, the efficacy of *B. thuringiensis* is affected by the length of exposure to ultra violet or solar radiation in the field (Becker *et al.*, 1992). The half-life of *B. thuringiensis* to solar radiation has been estimated at 3.8 hour (Dunkle & Shasha, 1989).

Bacillus thuringiensis also asserted its insecticide properties much slower than the chemical insecticides. Crystalline proteinaceous inclusions or the protoxins of *B. thuringiensis* need to be ingested by the targeted pest, or more precisely the target larvae prior the insecticide can take effect. Protoxin is in its inactivated form, upon ingestion, protoxins will be activated through a series of proteolytic process where the protoxins are solubilized in the alkaline mid gut fluid with pH more than 10, then reduce into toxins by specific proteases (Saxena *et al.*, 2010). Once activated, the active toxins interact with receptors on mid-gut epithelial cells, where the toxins form pores and destroy insects' cells by osmotic lysis (Deepak *et al.*, 2001). Thus, it is a process that would take at least a few days to a week. For area with severe outbreak of oil palm bunch moth, application of *B. thuringiensis* would not aid in suppressing the pest population even with multiple repeated applications.

Indoxacarb on the other hand attested slightly higher toxicity against oil palm bunch moth than *B. thuringiensis.* However, poorer performance as compared to chlorantraniliprole. Indoxacarb, methyl (S)-N-[7-chloro-2,3,4a,5-tetrahyro-4a-(methoxycarbonyl) indeno [1,2-e] [1,3,4] oxadiazin-2-ylcarbonyl]-4'-(trifluoromethoxy) carbanilate (Szpyrka *et al.*, 2017), which belongs to the oxadiazine group is a broad spectrum, non-systemic and synthetic organophosphate replacement insecticide, environmental compatibility and safety to non-target organisms (Wing *et al.*, 2000; Spomer *et al.*, 2009). Indoxacarb is touted by the industry as a reduced-risk insecticide, where target insects were affected through direct absorption into the insects' body or via ingestion of the treated fruit or foliage (Adriana, 2003). The mode of action of indoxacarb is by inhibiting the flow of sodium ions into the nerve cells of the target insects. The flow of sodium ions is essential for nervous system to function properly. Disruption of these channels causes tremors, cessation of feeding, paralysis and eventually death of the insect pests (Brugger, 1997; Parthiban *et al*., 2016).

Indoxacarb is not harmful to oil palm natural pollinators, *Elaeidobius kamerunicus* (Su, 2016) and its mode of action which differ from chlorantraniliprole and *B. thuringiensis,* has no known cross resistance with other organophosphates, carbamate and pyrethroids were among the reasons why it was chosen to be tested in this study. However, indoxacarb also exhibited short pesticides effect period and the use of it solely to curb *T. mundella* infestation is not recommended.

In general, all insecticides used in this study offered some extend of protection to all the oil palms against *T. mundella*. However, the results of optimal dosage of chlorantraniliprole trial demonstrated that chlorantraniliprole displayed the highest effectiveness in protecting oil palm from oil palm bunch moth. Chlorantraniliprole outperformed *B. thuringiensis* and indoxacarb, which yielded more clean to light fruit bunches than all other treatments. Chlorantraniliprole, is an anthranilic diamide insecticide developed by Du Pont de Nemours and Company, Inc. Chlorantraniliprole is effective against chewing insect pest primarily through ingestion and secondarily by contact through a very specific mode of action. Chlorantraniliprole activates the ryanodine receptors of the target pests vis stimulating the release of calcium from internal stores in the sarcoplasmic reticulum of muscle cells. This results impaired regulation, paralysis and ultimately death of the target insect (Lahm *et al.*, 2005; Lahm *et al.*, 2007; Axel *et al.*, 2009; Gustavo *et al.*, 2015).

The 30 g and 40 g chlorantraniliprole per ha with satisfactory control on oil palm bunch moth, *T. mundella* Walker as shown in this trial was a relatively low dosage required as compared to other fruit trees, vegetable crops, grapes and potatoes which needed 60 g chlorantraniliprole per ha to give considerable protection against pest (Axel *et al.*, 2009). The lower dosage needed to control oil palm bunch moth indicates the high effectiveness of chlorantraniliprole in controlling *T. mundella* and makes it an attractive choice as it will reduce the cost of pest management.

The longer pest control effect of the chlorantraniliprole noted in this study is consistent with the observation reported by Malaysia Palm Oil Board that plots treated with chlorantraniliprole could suppress *T. mundella* population at low level for more than 50 days after the last application (Saharul *et al.*, 2017). Longer lasting of chlorantraniliprole could relate to its high resistance to photo-degradation, rainfast nature and ability to move trans-laminar in the plant system as reported by Temple *et al.* (2009) and Chua *et al.* (2010). With this feature, chlorantraniliprole certainly will have advantage in region with no shortage of sunshine and high rainfall (2,500 mm per year in Sarawak).

The Efficacy of Different Dosages of Chromafenozide Rotated with Chlorantraniliprole

The reason chlorantraniliprole was chosen to rotate with chromafenozide in this study was due to the fact that it is designated as a reduced-risk pesticide by the United States Environment Protection Agency, which has demonstrated low intrinsic toxicity on honey bees and bumblebees (Axel *et al.*, 2009) and its high potent effect on *T. mundella* as demonstrated in the results obtained from optimal dosage of chlorantraniliprole trial. The very low mammalian toxicity with a favourable eco-toxicological profile, no cross-resistance issue with other conventional organophosphate and carbamate pesticides as well as highly efficacious against lepidopteran species at relatively low application rates has made chlorantraniliprole an ideal candidate for integrated *T. mundella* management in peat.

Chromafenozide, as an insect growth regulator is the most potent non-steroidal ecdysteroid agonist (Ahmed *et al.*, 2015; Saleh & Abdel-Gawad, 2018) of the dibenzoylhydrazine compound against a wide range of lepidopteran larvae namely Noctuidae, Pyralidae, Pieridae and Tortricidae (Ghoneim & Tanani, 2017). On the other hand, chromafenozide is relatively weak or inactive against Diptera and Coleoptera families and low toxicity profile towards mammals, birds, fishes as well as non-target arthropods such as predators, insect pollinators and parasitoids (Mikio *et al.*, 2006; Hadi *et al.*, 2008). Therefore, chromafenozide had the least harmful effect on the survival of newly emerged oil palm pollinator weevils. The narrow spectrum of insecticidal activity of chromafenozide makes it an excellent candidate for integrated pest management programmes. The repeating usage and the use of antagonistis mixtures of chemicals on season-long pest control would exacerbates pest resistance problem. Therefore, adoption of rotation mechanism by alternating different chemicals with different mode of actions are useful strategies to breakdown insecticide resistance problems (Ghoneim *et al.*, 2012). The results obtained from optimal dosage of chromafenozide rotated with chlorantraniliprole also revealed that chromafenozide with diferent mode of action from chlorantraniliprole would serve as a potential alternative insecticide in chemical rotation mechanism in controlling oil palm bunch moth, *T. mundella* in a more sustainable way. This application method applied in the oil palm plantation with severe pest outbreak would indirectly contribute to the pest resistant management where problems associated with resistant oil palm bunch moth strain to the available insecticides would not surface in near future.

In lepidopteran insects, the steroid hormone 20-hydroxyecdysone functions as a generalized systemic signal coordinating critical developmental events of embryogenesis, larval molting, metamorphosis and reproduction mechanism. When chromafenozide was applied on target lepidopteran insects, the compound acts like the steroid hormone 20-hydroxyecdysone by binding onto the ecdysteroid receptor complex of the insect and up or down regulate the expression of a series of genes that controls the molting progress (Hadi *et al.,* 2008). There were insignificant mean percentage of all the three categories namely, clean to light, moderately and severely infested fruit bunches among the three different doses rotated with chlorantraniliprole.

The results obtained from different chromafenozide dosage rotated with chlorantraniliprole strongly indicated that by rotating chromafenozide with chlorantraniliprole against oil palm bunch moth, a dose of 500 ml per ha is sufficient to have reasonable control on this particular pest compared to higher dose of 750 ml and 1,000 ml per ha. This makes chromafenozide a good candidate to be used in rotation with chlorantraniliprole.

CONCLUSION

Based on the results obtained from the optimal dosage of chlorantraniliprole trial, application of 30 g and 40 g a.i. per ha chlorantraniliprole outshined the rest and gave the longest control period. Considering the material cost per ha which is one of the most important criteria in pest management decision making, 30 g a.i. per ha of chlorantraniliprole is recommended as the optimum dosage to be adopted in controlling oil palm bunch moth in oil palm plantation planted on peat. When 30 g a.i per ha of chlorantraniliprole rotated with 25 g a.i. per ha chormafenozide in the following experiment with a total of four rounds in a year could yield more than 70% clean fruit bunches and less than 10% severely infested fruit bunches from 32 weeks onwards until the end of 52 weeks. With these results, rotation among insecticides with different mode of action seems promising. The recommended chemical rotation regime is 85 g product per ha of chlorantraniliprole 34.9% w/w used in rotation with 500 ml product per ha of chromafenozide. Further trials are recommended to test out the effectiveness of the combination these insecticides in supressing other pests in the oil palm plantation in order to formulate the most economic and effective oil palm pest management strategy.

ACKNOWLEDGEMENTS

The authors would like to thank Sarawak Oil Palms Berhad, Miri for support in the field work, and to Universiti Putra Malaysia Bintulu Sarawak Campus for the use of their facilities and technical supports. This research is funded by Grant Putra IPS GP-IPS/2017/9541400.

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